Building in a Fire-Prone Environment: Research on Building Survival in Two Major Bushfires

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This paper discusses some eleven years of research by the authors into the reasons why houses are ignited and subsequently destroyed in bushfires in Australia. Particular reference is made to fires which occurred in February 1983 and January 1994. The effect on various aspects of building design and construction are discussed on the basis of statistical data obtained by surveying the fate of houses in the 1983 fires and comparisons made with survey data, obtained up to the date of writing, from the 1994 fires.

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INTRODUCTION

In the twelve years since the major losses caused by the 'Ash Wednesday' fires of 16 February 1983 in Victoria and South Australia, much has been learnt about the mechanisms involved in the ignition and destruction of buildings by bushfires. This information forms the basis for Australian standards and advice on building design and construction in bushfire-prone areas as part of an integrated approach, involving vegetation management, subdivision and landscape design.

In the 'Ash Wednesday' fires 76 people died, and 2463 houses, more than 100 farm buildings, 30 000 stock, 20 000 km of fencing and 1.5 million bales of hay were destroyed. Monetary damage had been estimated to be in excess of A$440 million (Anon. 1983). Such bushfires are an inevitable part of living in the urban–rural interface in Australia and this has been highlighted by the recent January 1994 fires in New South Wales (NSW) where significant losses occurred. In these fires 4 people died, 206 houses were destroyed and the estimated damage was in excess of $100 million.

The challenge of providing adequate safety for buildings and their occupants is increasing in importance as more houses are being built in urban–rural interfaces throughout Australia and the bush itself is being preserved rather than cleared or replaced by exotic species. This paper summarises research carried out by the authors since the 1983 'Ash Wednesday' fires and details preliminary results of investigations of the 1994 NSW fires. Another survey of note was carried out by Wilson (1984) after the 1983 fires, but no attempt is made in this paper to compare the results.

SURVEYS OF BUILDING PERFORMANCE

Two extensive surveys of the performance of buildings in bushfires have been carried out by the authors. The first (Ramsay et al. 1986) was of 1148 buildings involved in the Otway Ranges (Victoria) fire which was one of the many fires which occurred on 'Ash Wednesday' 1983. The second survey is of buildings involved in three of the areas affected by the NSW 1994 fires in the Sydney metropolitan area: Como–Jannali, Cottage Point and Lane Cove. This survey is not complete, with 469 houses having been surveyed and some 50 still to be surveyed.

As indicated in Table 1, the proportions of houses in the two surveys which were threatened but 'not ignited', 'damaged' to varying degrees or 'destroyed' and not repairable, varied. The houses fared better in the NSW fires and various factors, some of which are discussed below, could explain these differences, even though their relative importance has not yet been evaluated.

The large number of houses involved in the Otway Ranges fire, the evenness of fire attack and the wide spread of building design and materials meant that statistical analysis (Ramsay et al. 1986) of the data collected was appropriate. However, the data from the NSW fires are small in terms of the three areas being surveyed and the construction of the houses were similar and did not give a wide spread of materials; it is thus not envisaged that statistical analysis will be appropriate. In both surveys, over 80 data elements were collected on each house and its surroundings. These data elements provided information on the various elements of the buildings and their surroundings, including roofs, walls, windows, floors, decks, colour, outbuildings, the site and the vegetation.

TABLE 1

Classification of damage

Classification	Otway Ranges survey No.	Otway Ranges survey %	NSW survey No.	NSW survey %
Not ignited	433	38	284	61
Damaged	92	8	56	12
Destroyed	623	54	119	25
Unknown	0	0	10	2
Total	**1148**	**100**	**469**	**100**

STASTICAL ANALYSIS OF OTWAY RANGES FIRE AND COMPARISON WITH THE NSW FIRES

In the following discussion, representative results of the Otway Ranges statistical analysis are discussed with appropriate preliminary comments on the NSW survey. The statistical analysis was carried out by fitting the data to a logistic model. A base model was developed using data elements selected on the basis of simple tabulations and additional data elements added individually to assess their significance (a 95% confidence level was used).

Wall Cladding

Previous surveys have come to conflicting conclusions regarding the role of wall cladding, e.g. the survey of the Beaumaris fires (Barrow 1944) indicated that cladding did not appear to play a role, whereas the Hobart–Blue Mountains survey (Anon. 1979) indicated that masonry cladding was best.

Table 2, based on the Otway Ranges survey, shows the results of the statistical analysis in terms of the relative risk of houses being destroyed (RRD) for houses with various claddings, with houses clad with timber taken as the base (i.e. relative risk for timber is assigned a value of 1.0). An RRD value of 0.5 would indicate that a house with a particular feature would be twice as likely to survive compared to a house with the 'base' feature. Generally, differences greater than 0.2 were considered to be significant. These data indicate that a house clad with masonry is less likely to be destroyed than one clad with fibre-cement sheet or timber which have similar although not identical RRD values. It may be argued that this may not only be a function of the actual material used but also related to the designs typical of houses with these cladding materials. For example, masonry-clad houses do not generally have an unenclosed subfloor space, whereas timber-clad houses do. However, the logistic model used for the statistical analysis takes the possibility of such interactions into account.

The results obtained for the NSW survey (Table 3) indicate that masonry-clad houses again fared best, but the data for the small number of houses (16%) with other than masonry walls have to be treated with caution.

There is a widely held belief that the colour of wall cladding plays a role in house survival and that white-coloured walls are beneficial in that they reflect the heat of the bushfire better than dark-coloured walls. The data from the Otway Ranges survey (see Table 4) do not support this view.

TABLE 2

Otway Ranges survey – effect of wall cladding

Cladding	Relative risk of destruction*
Masonry	0.4
Fibre cement	0.8
Timber	1.0

* 'Timber' assigned a reference value of 1.0.

TABLE 3

NSW survey — effect of wall cladding

Cladding	% for each material			
	Not ignited	Damaged	Destroyed	Unknown fate
Masonry	68	13	17	2
Fibre cement	52	15	31	2
Timber	35	8	58	0

TABLE 4

Otway Ranges survey – effect of wall cladding colour

Colour	Relative risk of destruction*
White	1.0
Light or pastel	0.8
Medium	0.9
Dark	0.9

* 'White' assigned a reference value of 1.0.

Roof Cladding

Several aspects of roofing were examined. In the Otway Ranges survey, houses with masonry tile or steel deck roofs survived more often than those with corrugated iron or fibre-reinforced cement roofs (Table 5), but the pitch of the roof did not appear to affect survival (Table 6). The latter finding is contrary to previously published advice (Barber and Morris 1983) which suggests that houses with high-pitched roofs are at greater risk than those with low-pitched roofs.

Table 7 shows data for the roof cladding material for the NSW survey. Tiled roofs again fared best; the relatively small numbers of steel deck (6%) and corrugated iron roofs (6%) makes differentiation of their behaviour difficult.

TABLE 5

Otway Ranges survey – effect of roof cladding

Cladding	Relative risk of destruction*
Tiles	0.4
Steel deck	0.7
Corrugated iron	0.9
Fibre cement	1.0

* 'Fibre cement' assigned a reference value of 1.0.

TABLE 6

Otway Ranges survey – effect of roof slope

Cladding	Relative risk of destruction*
Pitched (>12°)	0.8
Flat (<12°)	1.0

* 'Flat' assigned a reference value of 1.0.

TABLE 7

NSW survey – effect of roof cladding

Cladding	% for each material			
	Not ignited	Damaged	Destroyed	Unknown fate
Tiles	71	11	16	2
Corrugated iron	41	26	33	0
Steel deck	32	14	50	4

Degree of Elevation

The effect of the degree of elevation of the houses was examined as indicated in Table 8 for the Otway Ranges survey; houses on normal height stumps were elevated less than the 'low' category. It was found that houses on stumps were most likely to be destroyed, whereas houses built on concrete slabs were least likely; the other categories showed intermediate performance. The vulnerability of houses on stumps appeared to be due to factors such as the use of timber gap-boards to enclose the underfloor space of timber and fibre-reinforced-cement-clad houses, and the use of (timber) stumps at spacings closer than that used for other means of (greater) elevation.

TABLE 8

Otway Ranges survey — effect of degree of elevation

Elevation	Relative risk of destruction*
None (slab-on-ground)	0.2
High (>2 m)	0.4
Low (<2 m)	0.5
Stumps	1.0

* 'Stumps' assigned a reference value of 1.0.

Occupant Action

Two-thirds of the houses in the Otway Ranges survey were unoccupied on the day of the fire and very few of the remaining people actually stayed with their houses during the fire. However, those who returned to their houses after the fire front had passed were able to improve the chances of the survival of their houses and to diminish the damage sustained. Table 9 shows the beneficial effect of the presence of people and their fire-fighting activities and supports the information obtained by interview. People other than occupants also saved houses from destruction; the inclusion of these cases in the data of Table 9 would increase the statistical significance of the first two categories.

Personal interviews revealed that people were able to save their houses by extinguishing burning materials around the houses – woodheaps, fence posts, trees and other burning buildings – and by extinguishing small ignitions of the house itself before these small fires became uncontrollable. In many cases, residents carried out these salvage operations on their own houses and their neighbours' houses after the fire front had passed. Further houses were saved by fire brigade action, although because of the speed of the fire such actions were generally limited.

A similar picture is emerging from the NSW survey, but the amount of fire brigade activity was considerably greater, with the opportunity to minimise the attack on the housing and actually extinguish houses which had started to burn.

TABLE 9

Otway Ranges survey – effect of occupant action

Action	Relative risk of destruction*
Stayed	0.1
Left — returned within half an hour	0.4
Left — stayed away	0.6
Unoccupied — at time of fire	1.0

* 'Unoccupied' assigned a reference value of 1.0.

Vegetation

The amount and type of vegetation around the houses was found to be an important factor (see Table 10 for the Otway Ranges survey). Houses were more likely to be destroyed as the vegetation (no differentiation was made between 'natives' and 'exotics') around them became thicker and the proportion of trees to shrubs increased and presumably the fire intensity increased. This analysis did not take into account the 'housekeeping' on the property, i.e. the degree of clearing of undergrowth, grasses, leaf debris, etc., because in most cases the fire had destroyed the evidence. One would expect the amount of ground fuel would thus be a reflection of the density of vegetation and number of trees.

A similar picture emerges from the NSW survey, as shown in Table 11, and similar conclusions may be drawn.

TABLE 10

Otway Ranges survey – effect of surrounding vegetation

Vegetation type	Relative risk of destruction*
Grass	0.1
Shrubs	0.4
Trees	1.0

* 'Trees' assigned a reference value of 1.0.

TABLE 11

NSW survey – effect of surrounding vegetation

Vegetation type	% for each type			
	Not ignited	Damaged	Destroyed	Unknown fate
Grass	71	9	18	2
Shrubs	61	17	19	3
Tree	43	12	43	2

Area of Glazing

Windows are thought to be the most vulnerable part of a wall in that they may break and allow burning debris to ignite the interior of the house. The NSW survey has provided an opportunity to study the role of windows. Table 12 summarises data on the effect of glass area (in the wall with the greatest per cent of glass). There is a pronounced trend of increasing destruction with increasing per cent glass area, which is in accord with the perceived role of windows in house destruction.

TABLE 12

NSW survey – effect of area of glass (in wall with greatest % of glass)

Area of glass (%)	% for each category			
	Not ignited	Damaged	Destroyed	Unknown fate
<30	85	9	5	1
30–50	75	12	10	3
50–80	54	23	21	2
>80	36	14	50	0

MECHANISMS OF IGNITION AND DESTRUCTION

During the course of gathering data for the surveys, particular attention was given to gathering information on how the houses might have been ignited and thus ultimately destroyed. This was done by examining the houses themselves, particularly those which had been damaged but not destroyed, and interviewing occupants and fire brigade personnel. In the majority of cases the damaged houses had been saved by firefighting activities and the 'ignition points' were thus an indication of where the destroyed houses may have been ignited. The conclusions drawn are discussed in the following paragraphs.

'Exploding' Houses

In the 1983 'Ash Wednesday' and 1994 NSW fires as well as previous bushfires, there have been accounts of houses spontaneously exploding due to the heat of the fire front. However, examination of the remains of destroyed houses and interviews with people present during the fires did not substantiate these claims. From the theoretical viewpoint, such 'spontaneous explosions' are improbable. Because of the speed with which the fire front travels, a house is exposed to the heat of the fire front for only a few minutes and this would not appear to be sufficient to cause 'instantaneous' ignition and total involvement of a house in flames.

Modes of Ignition

There are three possible modes of ignition – burning debris lodging on combustible material, radiation from the fire and direct flame contact: all three modes appeared to play a part in house destruction.

Evidence for the modes of ignition in both surveys came mainly from surviving houses and interviews with eyewitnesses who had been in the area (but not necessarily occupying the houses). In the majority of cases, ignition appeared to have been caused by burning debris, although radiant heat and flame played a significant role in cases where the houses were directly abutting dense undeveloped vegetation. The burning debris attacked houses for some time before, and for many hours after, the fire front passed, whereas the fire front itself impinged upon the houses for only several minutes.

Burning debris can gain entry to a house through broken windows or gaps in and around the wall or roof cladding, and then ignite the contents. The burning debris lodges on and ignites horizontal timber in decks, steps and windowsills, or is blown up against and ignites timber used at ground level for stumps, gap-boards, posts and steps.

Thermal radiation may crack windows, allowing burning debris to enter; it can heat the building and its contents, facilitating ignition by embers or flame; and, in extreme cases, it can ignite external timber or combustible contents near broken windows.

Evidence for flame contact by the fire front was difficult to find and apparent evidence, such as charred wood, was ambiguous because it may have been the result of radiation or of the ignition of vegetation growing against a house.

The ignition and destruction of the houses was facilitated by the strong winds which accompanied the fires. The wind carried the burning debris as well as large objects capable of breaking windows. In some cases, the force of the wind 'opened-up' houses to burning debris by removing roofs and walls.

CONCLUSIONS

The results emerging from the survey of the performance of buildings in the NSW fires of January 1994 are similar to those obtained in previous surveys, especially that carried out on the Otway Ranges fire which occurred on 16 February, 1983.

Similar house design and material factors appear to be operating, and the fact that the majority of houses involved in the NSW fires were brick-clad with tiled roofs appears to account, at least in part, for the greater proportion of surviving houses. The significant firefighting effort appears to be another contributing factor.

The ignition agents – burning debris, radiant heat and flame – are also similar, with their relative importance varying according to the relationship of the house to areas of vegetation. However, burning debris appeared to play a role in all circumstances. Ignitions are aided by the wind carrying the burning debris and large objects capable of breaking windows.

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REFERENCES

Anon. (1979). 'Houses Exposed to Bushfires'. Notes on the Science of Building No. 154, Experimental Building Station. (Department of Housing and Construction: Australia).

Anon. (1983). *Australian and New Zealand Burn Association J.* **6**: 39.

Barber, J. and Morris, W. (1983). 'Design and Siting Guidelines: Bushfire Protection for Rural Houses'. (Department of Planning and Country Fire Authority of Victoria).

Barrow, G.J. (1944). A Survey of Houses Affected in the Beaumaris Fire, January 14, 1944. *J. CSIR* **18**: 27.

Ramsay, G.C., McArthur, N.A. and Dowling, V.P. (1986). Building survival in bushfires. *Proceedings of Fire Science '86, 4th Australian National Biennial Conference, 21–24 October*, The Institution of Fire Engineers.

Wilson, A.A.G. (1984). 'Assessing the bushfire hazard of houses: a quantitative approach'. Tech. Paper No. 6. (National Centre for Rural Fire Research, Chisholm Institute of Technology: Victoria).